PREDICTIVE MICROBIOLOGICAL MODELS: WHAT ARE THEY AND HOW CAN THEY BE USED IN THE FOOD INDUSTRY?

WHY USE MODELS?

Predictive microbiological models are tools that can be used to assess product shelf-life and safety. Models can also be used:

- In product development
- To identify areas where challenge testing should be undertaken
- As a tool with HACCP and risk assessment plan development

THE SCIENCE

Predictive microbiological models are computer based software packages which allow the user to estimate the rate of microbial growth or get an indication of whether growth of a particular microorganism will occur under a specified set of conditions.

The models are based on laboratory generated data. Microbiological growth media (broths) are produced with different instrinsic parameters such as pH and salt level and are then inoculated with the relevant organism or cocktail of organisms. These broths are then stored at a range of temperatures and the microbial level present is assessed over time. These are known as **kinetic growth models**, as they allow assessment of the amount of growth that can occur.

A different approach is to note time to turbidity rather than assess microbial levels. These are **growth/no growth** or **time to growth models**, as they cannot estimate the level of growth, but simply if growth occurs.

Once the data is generated, statistical equations are fitted and these are then combined with a user-friendly interface.

Predictive models have been developed for both spoilage and pathogenic organisms and there are both growth and survival models available for use. The models will usually include the following variables:

- Temperature of storage, including fluctuating temperatures.
- pH.
- Salt or equivalent water activity.

Some models also take into account levels of preservatives such as nitrite, CO_2 and lactic and acetic acid.

Once parameters have been entered into the system, a prediction is produced. The prediction will usually be in the form of a growth curve (Figure 1), but parameters such as lag time, time to reach a specified microbial level and level at a specified time can also be predicted.

THE APPLICATION

Predictive models are a very quick, efficient and cost effective way of assessing the potential for growth of microorganisms under specific conditions without needing practical studies.

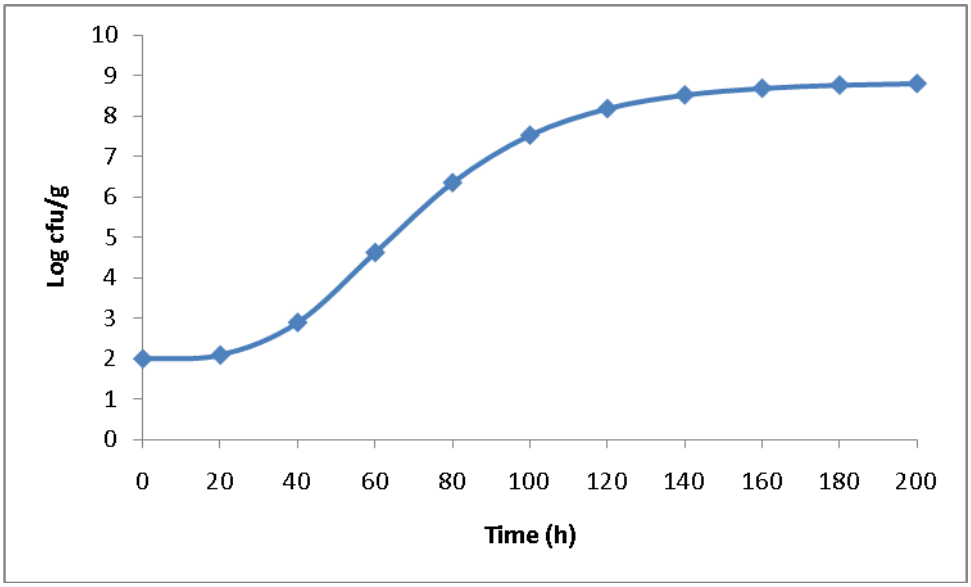
During product development, a product formulation may be changed several times before being finalised. Often there can be a pressure on time and money and therefore it is not possible to practically evaluate the shelf life of all possible formulations. It is important that the potential for growth and/or survival of all relevant organisms is assessed and practical trials are carried out on the final formulation. However, limiting the amount of practical work required will save time and money.

It is not only during product development that the potential for microbial growth is important; other examples include a product being subjected to a slightly elevated temperature or if there has been a problem with formulation of a batch of product.

With regards to spoilage organisms it is usually the time to reach a specified target level that is the most important parameter. However, for pathogenic organisms such as *Salmonella* or *C. botulinum*, it is the time for growth to begin (lag time) that is the most important parameter as any growth at all has to be avoided. For some organisms like *S. aureus* and *B. cereus*, which produce toxins and cause food poisoning when a specified level is reached, predictive systems can be used to predict the time taken to reach these levels. Predictive systems can also be used to predict if *Listeria monocytogenes* could reach a level of 100 cfu/g during a product's shelf life (the limit set in EU hygiene legislation).

Growth of spoilage organisms can be modelled using a Campden BRI developed system known as FORECAST. Also included in the FORECAST system are models covering specific food commodities. These models are based on the specific spoilage organisms for the relevant food commodity. There are currently models for fish, meat, fresh produce and yeasts in fruits and drinks, plus a range of models relevant to acidified foods. The acidified foods models and yeast in fruit and drinks, Bacilli and mould models give predictions of time to growth rather than producing growth curves.

Figure 1
Microbial growth curve



Predictions are carried out by Campden BRI and a report including growth curves and time to reach specified levels is produced and interpreted for the Client.

In order for a prediction to be produced, the client must provide the following information: pH, water activity, % salt (all can be measured at Campden BRI) and temperature (either one static temperature or a fluctuating profile). Campden BRI can then advise as to which organisms or commodity models would be most relevant. For some models such as the acidified food models, level of preservative is also required. The models currently available in the FORECAST system are detailed below in Tables 1 and 2.

Acid tolerant organisms

The models developed for acidified foods are based on 3 groups of organisms. These models have been termed: cold fill spoilage, which includes acid adapted yeasts, moulds and lactic acid bacteria; cold fill pathogens, which includes *E. coli,*
S. aureus and *Salmonella*; and hot fill spoilage, which includes sporeformers such as
B. coagulans and *C. pasteurianum*.

Predictions generated from these models are based on 5 categories: category 1 growth in 1-14 days, category 2 growth in 15-30 days, category 3 growth in 31-60 days, category 4 growth 61-182 days, category 5 no growth in 6 months.

Data was produced and models were generated based on pH, Aw and preservative level as detailed in Table 2.

Safety and stability of acetic acid based mayonnaises and sauces can also be assessed using the equations given in the CIMSCEE code. There are safety and stability formulae, both of which are based on pH, and amounts of acetic acid, salt and sugar in the water phase. A numerical value is calculated which has to be greater than 63 for the product to be considered safe and/or stable.

Campden BRI is able to perform these calculations for clients. If the required values are not available, Campden BRI can analyse products for salt, sugar, water, pH and acetic acid level.

Food pathogens

Pathogen predictions can be carried out using the Combase predictor system. This system is internet based and predictions are generated online. This system is freely available via https://browser.combase.cc/ComBase_Predictor.aspx?model=1 (2.1.18)

Campden BRI is able to generate pathogen predictions using Combase predictor and interpret them for clients who do not have a microbiological background. The Combase system contains growth models but also thermal death models. These thermal death models predict log reductions of an organism at a specified temperature. There are also survival models for *Salmonella* and *Listeria* which predict the log reduction of the organism at various pH values, temperatures and salt levels. This can be useful to assess if pathogens can survive in, for example, acidified foods. Another useful model is one that allows the potential for *C. perfringens* growth to be predicted during cooling. The details of models and input parameters for models contained in the Combase predictor system are detailed in Tables 3 and 4.

A further set of pathogen models in the USA, known as the pathogen modelling program (PMP), is freely available via the internet. Details of the models included are given in Table 5. These can be generated online at *https://pmp.errc.ars.usda.gov/PMPOnline.aspx* (2.1.18) or a software package can be downloaded for stand-alone use. The stand alone system (v 7.0) has more models available for use than the online system https://www.ars.usda.gov/northeast-area/wyndmoor-pa/eastern-regional-research-center/residue-chemistry-and-predictive-microbiology-research/docs/pathogen-modeling-program/pathogen-modeling-program-models/ (2.1.18)
Details of these additional models are given in Table 6.

For further information on how models can be used, contact:

Linda Everis
Tel: 01386 842063
Fax: 01386 842100
Email: Linda.everis@campdenbri.co.uk

or,

Gail Betts
Tel: 01386 842071
Fax: 01386 842100
Email: Gail.betts@campdenbri.co.uk

Table 1
Spoilage models available in FORECAST

Model	Temperature (°C)	NaCl (% aq)	Equivalent Aw	pH	Other Conditions
Pseudomonas	0 - 15	0.0 - 4.0	1.00 - 0.977	5.5 - 7.0	Fluctuating temperature, pH, salt
Bacillus spp.	5 - 25	0.5 - 10	0.997 - 0.935	4.0 - 7.0	Fluctuating temperature, pH, salt
Enterobacteriaceae	0 - 27	0.5 - 10	0.997 - 0.935	4.0 - 7.0	Fluctuating temperature, pH, salt
Yeasts (chilled foods)	0 - 22	0.5 - 10	0.997 - 0.935	2.6 - 6.0	Fluctuating temperature, pH, salt
Yeasts (fruit/drinks) (time to growth)	0 - 22	-		2.0 - 7.0	0 - 60% Sucrose (w/v) 0 - 20% Ethanol (v/v) Potassium sorbate 0 - 1000(ppm)
Lactic acid bacteria	2 - 30	0.5 - 10	0.997 - 0.935	3.0 - 6.0	Fluctuating temperature
Meat spoilage	2 - 22	0 - 6	1.00 - 0.964	4.6 - 7.0	0 - 240 KNO_2 (ppm) Fluctuating temperature, pH, salt
Fish spoilage	2 - 22	0 - 6	1.00 - 0.964	4.5 - 8.0	Fluctuating temperature, pH, salt
Fresh produce TVC	2 - 25	-	-	-	
Fresh produce Enterobacteriaceae	2 - 25	-	-	-	
Fresh produce lactic acid bacteria	2 - 25	-	-	-	
Fresh produce *Pseudomonas*	2 - 25	-	-	-	
Enterobacteriaceae death model	52 to 64	0 - 8	1.00 - 0.95	4.0 - 7.0	Predicts D value
Bacillus (time to growth)	8 - 45	0.5 - 10	0.997 - 0.935	4.0 - 7.0	
Bacillus (growth or no growth)	5 - 45	1.33-17.5	0.845-0.988	3.48-5.03	
BBQ sauce	5 or 25	0-3	-	-	Sugar (sucrose) 0-50%, acetic acid 0.5-4.0%, sorbate 0-2000ppm
Juice	8	-	-	2.5-4.0	Sweetener presence-Y/N Preservative presence-Y/N Sugar (sucrose) 10-50% Juice 0-25%
Aspergillus niger	NA	NA	0.80-0.97	4.67-7.56	K sorbate and Ca propionate 0-0.5%
Aspergillus	NA	NA	0.80-0.97	4.67-7.56	K sorbate and Ca

ochraceus					propionate 0-0.5%
Cladosporium herbarium	NA	NA	0.80-0.97	4.67-7.56	K sorbate and Ca propionate 0-0.5%
Eurotium repens	NA	NA	0.80-0.97	4.67-7.56	K sorbate 0-0.5%
Mucor racemosus	NA	NA	0.80-0.97	4.67-7.56	K sorbate and Ca propionate 0-0.5%
Penicillium corylophilium	NA	NA	0.80-0.97	4.67-7.56	K sorbate and Ca propionate 0-0.5%
Penicillium aurantiogriseum	NA	NA	0.80-0.97	4.67-7.56	K sorbate and Ca propionate 0-0.5%
Rhizopus spp	NA	NA	0.80-0.97	4.67-7.56	K sorbate and Ca propionate 0-0.5%

Table 2
Models for acidified foods in FORECAST

Organisms	Prediction categories/time to growth (G)	pH	Aw	Salt % w/v	Preservative ppm
Cold fill spoilage (yeasts, moulds, lactics)	1 = G in 14d 2 = G in 15 - 30d 3 = G in 31 - 60d 4 = G in 61 - 182d 5 = NG in 182d	2.8 - 5.0	0.85 - 1.00	0.5 - 18	Benzoate Sorbate 0 - 2000 (in total)
Cold fill pathogens (*E. coli, S. aureus, Salmonella*)	1 = G in 120d 2 = NG in 120d	3.9 - 5.0	0.87 - 1.00	0.5 - 16	Benzoate Sorbate 0 - 2000 (in total)
Hot fill spoilage (sporeformers)	1 = G in 14d 2 = G in 15 - 30d 3 = G in 31 - 60d 4 = G in 61 - 182d 5 = NG in 182d	3.7 - 5.2	0.86 - 1.00	0.5 - 18	Benzoate Sorbate 0 - 2000 (in total)

Key: G = Growth
NG = No Growth

Table 3
Combase Predictor growth models

Model	Temperature (°C) (fluctuating temperature profiles can be used)	NaCl (% aq)	Aw	pH	Other conditions (only one extra condition permitted per prediction)
Aeromonas hydrophila	2 - 37	0.0 - 4.5	1.00 - 0.974	4.6 - 7.5	-
Bacillus cereus	5.0 - 34.0	0.0 - 9.4	1.00 - 0.94	4.9 - 7.4	CO_2 0 - 60%
Bacillus licheniformis	13.0 - 34.0	0.0 - 13.5	1.00 - 0.907	4.0 - 7.6	-
Bacillus subtilis	10.0 - 34.0	0.0 - 10.3	1.00 - 0.933	4.3 - 7.8	-
Brochothrix thermosphacta	0.0 - 30.0	0.0 - 8.0	1.00 - 0.95	5.5 - 7.0	-
Clostridium botulinum (non-proteolytic)	4.0 - 30.0	0.0 - 4.5	1.00 - 0.974	5.1 - 7.5	-
Clostridium botulinum (proteolytic)	14.0 - 40.0	0.0 - 7.5	1.00 - 0.954	4.7 - 7.2	-
Clostridium perfringens	15.0 - 52.0	0.0 - 5.0	1.00 - 0.971	5.0 - 8.0	-
E. coli	10.0 - 42	0.0 - 6.5	1.00 - 0.961	4.5 - 7.5	0 - 100% CO_2
Listeria monocytogenes/ innocua	1.0 - 40	0.0 - 10.2	1.00 - 0.934	4.4 - 7.5	0 - 100% CO_2
Listeria monocytogenes/ innocua	1.0 - 40	0.0 - 11.4	1.00 - 0.924	4.4 - 7.5	0 - 20,000ppm lactic acid 0 - 10,000ppm acetic acid 0 - 200ppm $NaNO_2$
Salmonella	7.0 - 40	0.0 - 4.6	1.00 - 0.973	3.9 - 7.4	0 - 100% CO_2 0 - 200ppm nitrite
Staphylococcus aureus	7.5 - 30.0	0.0 - 13.5	1.00 - 0.907	4.3 - 7.1	-
Yersinia enterocolitica	-1 - 37.0	0.0 - 7.0	1.00 - 0.957	4.4 - 7.2	0 - 10,000ppm lactic acid 0 - 80% CO_2
Pseudomonas	0 - 20	0 - 6.5	0.961	5 - 7.4	
Shigella flexneri	15 - 37	0 - 5	0.971	5.5 - 7.5	0 - 1000 NO_2

Non thermal death	Temp (°C)	pH	NaCl (%)	Aw
L. monocytogenes/ innocua	0 - 20	3.5 - 7.0	0 - 25	0.793 - 1.0
Salmonella	0 - 40	4.3 - 7.5	0 - 26	0.781
Salmonella in eggs	10-42	7.6-8.0	-	0.995-1.00
Perfringens predictor - cooling model				
Cured/uncured	pH 5.2 - 8.0		0 - 4% NaCl	

Table 4
Combase Predictor thermal death models

Model	Temperature (°C)	NaCl (% aq)	Aw	pH
Bacillus cereus	90 - 100	2.5 - 7.5	0.986 - 0.954	4.5 - 7.0
Clostridium botulinum (non-proteolytic)	80 - 95	0 - 5.0	1.00 - 0.971	4.1 - 7.3
E. coli	54.5 - 64.5	0 - 8.4	1.00 - 0.947	4.2 - 8.0
Listeria monocytogenes/innocua	60 - 68	0 - 9.0	1.00 - 0.943	4.2 - 7.0
Salmonella	54.5 - 65	0 - 0.6	1.00 - 0.997	4.0 - 7.1
Yersinia enterocolitica	52 - 60	0.65	1.00 - 0.961	4.2 - 7.0
Brochothrix	40 - 55	0 - 2.0	1.00 - 0.989	5 - 7.0

Table 5
Models included in the Pathogen Modelling program on-line version

PMP Growth Models - Broth Culture						
Model	**Temp (°C)**	**NaCl (% aq)**	**Aw**	**pH**	**Initial level (log cfu/g)**	**Other conditions**
Aeromonas hydrophila aerobic	5 - 42	0.5 - 4.5	0.997 - 0.974	5.3 - 7.3	3 - 5.9	0 - 150ppm $NaNO_2$
Aeromonas hydrophila anaerobic	5 - 30	0.5 - 3.5	0.997 - 0.980	5.3 - 7.3	3 - 5.9	0 - 150ppm $NaNO_2$
Bacillus cereus aerobic	5 - 42	0.5 - 5.0	0.997 - 0.970	4.7 - 7.5	3 - 5.9	0 - 150ppm $NaNO_2$
Bacillus cereus anaerobic	10 - 42	0.5 - 5.0	0.997 - 0.970	5.0 - 9.0	3 - 5.9	0 - 150ppm $NaNO_2$
Escherichia coli O157:H7 aerobic	5 - 42	0.5 - 5.0	0.997 - 0.970	4.5 - 8.5	3 - 5.9	0 - 150ppm $NaNO_2$
Escherichia coli O157:H7 anaerobic	5 - 42	0.5 - 5.0	0.997 - 0.970	4.5 - 8.5	3 - 5.9	0 - 150ppm $NaNO_2$
Listeria monocytogenes (NaCl) aerobic	4 - 37	0.5 - 10.5	0.997 - 0.928	4.5 - 7.5	3 - 5.9	0 - 150ppm $NaNO_2$
Listeria monocytogenes (NaCl) anaerobic	4 - 37	0.5 - 5.0	0.997 - 0.970	4.5 - 8.0	3 - 5.9	0 - 150ppm $NaNO_2$
Staphylococcus aureus aerobic	10 - 42	0.5 - 12.5	0.997 - 0.911	4.5 - 9.0	3 - 5.9	0 - 150ppm $NaNO_2$
Staphylococcus aureus anaerobic	12 - 42	0.5 - 16.5	0.997	5.3 - 9.0	3 - 5.9	0 - 150ppm $NaNO_2$
Shigella flexneri aerobic	10 - 37	0.5 - 5.0	0.997 - 0.970	5.0 - 7.5	3 - 5.9	0 - 150ppm $NaNO_2$
Shigella flexneri anaerobic	12 - 37	0.5 - 4.0	0.997 - 0.977	5.5 - 7.5	3 - 5.9	0 - 150ppm $NaNO_2$
Other Models						
Model		**Input factors**			**Capabilities**	
L. monocytogenes transfer-		Inoculation level (log cfu/g per blade)			Calculates *L. monocytogenes*	

salmon	Temperature (°C) Attachment time (mins) A list of potential combinations is given	level on slices of ground salmon from slice 1 - 40
L. monocytogenes transfer- deli meat	Various inoculation levels – meat to blade	Calculates *L. monocytogenes* level on ham slices
L. monocytogenes shrimp and crab salad	Aerobic/Anaerobic 0-28 days Initial seafood contamination 4-12°C	Calculates growth rate and lag phase
L. monocytogenes smoked salmon	Salt 0-8% Phenol 0-34ppm 4-25°C	Calculates growth rate and lag phase
Salmonella Dublin- sterile ground chicken burger	0-13h 6 log cfu/g initial loading 10-44°C	Calculates Count v time
Salmonella Enteritidis- sterile ground chicken burger	0-13h 6 log cfu/g initial loading 12-46°C	Calculates Count v time
Salmonella Hadar sterile chicken skin	0-8h 6 log cfu/g initial loading 5-50°C	Calculates Survival log v number
Salmonella Kentucky sterile chicken skin	0-8h 6 log cfu/g initial loading 5-50°C	Survival log v number
Salmonella Typhimurium- chicken frankfurters	0-92h 10-40°C	Calculates Count v time
Salmonella Typhimurium- chicken skin	0-10 days 4-12°C	Calculates Log growth
Salmonella Typhimurium- sterile ground chicken portions	0-65h 6 log cfu/g initial loading 10-40°C	Calculates Count v time
Salmonella Typhimurium- sterile ground chicken burgers	0-10h 6 log cfu/g initial loading 10-48°C	Calculates Count v time
Salmonella spp in ground chicken	10-45°C	Calculates Growth rate
Yersinia pseudotuberculosis in ground beef	3.5-35°C	Calculates growth rate and lag phase
Survival		
Model	**Input factors**	**Capabilities**
E.coli O157 in cooked ham	8-15°C Sodium lactate 0-3%	Average Growth Rate log cfu/day
E.coli O157 in fermented sausage	Fermentation :pH 4.6- 6.0	Log cfu/g reduction
E.coli O157 in fermented sausage	Drying : pH 4.6- 6.0 Aw 0.84- 0.95	Log cfu/g reduction
E.coli O157 in fermented sausage	Storage: pH 4.6- 6.0 Aw 0.84- 0.95 4-30°C	Log cfu/g reduction
L. monocytogenes in cooked ham	Sodium lactate 0-3%	Average Growth Rate log cfu/day
L. monocytogenes in fermented sausage	Fermentation :pH 4.6- 6.0	Log cfu/g reduction
L. monocytogenes in fermented sausage	Drying : pH 4.6- 6.0 Aw 0.84- 0.95	Log cfu/g reduction
L. monocytogenes in fermented	Storage:	Log cfu/g reduction

sausage	pH 4.6- 6.0 Aw 0.84- 0.95 4-30°C	
L. monocytogenes smoked salmon	Smoking: Salt 0-6% Phenol 0-15ppm 40-50°C	Calculates inactivation rate
Salmonella spp in cooked ham	Sodium lactate 0-3% 10-15°C	Average Growth Rate log cfu/day
Salmonella Typhimurium in fermented sausage	Fermentation :pH 4.6- 5.4	Log cfu/g reduction
Salmonella Typhimurium in fermented sausage	Drying : pH 4.6- 5.4 Aw 0.84- 0.95	Log cfu/g reduction
Salmonella Typhimurium in fermented sausage	Storage: pH 4.6- 5.4 Aw 0.84- 0.95 4-30°C	Log cfu/g reduction
Cooling		
C.botulinum in broth	Temperature profile	Log cfu/g increase
C.perfringens in cured pork	Temperature profile Initial level 1.0-6.0 log cfu/g	Log cfu/g increase
C.perfringens in uncured pork	Temperature profile Initial level 1.0-6.0 log cfu/g	Log cfu/g increase
C.perfringens in cooked beef	Temperature profile NaCl 0-3% Nitrite 0-200ppm Initial level 1.0-6.0 log cfu/g	Log cfu/g increase
C.perfringens in uncured beef	Temperature profile	Log cfu/g increase
C.perfringens in uncured chicken	Temperature profile	Log cfu/g increase
Heat Inactivation		
E.coli in ground beef	54.5 - 63°C Tea extracts	D value and lag phase
L. monocytogenes in ground beef	Sodium lactate 0-4.8% Sodium diacetate 0-0.25% 60 - 74°C	D value and lag phase
L. monocytogenes in simulated beef gravy	pH 4.0- 7.0 NaCl 0-6% Sodium pyrophosphate 0-3% 55 - 65°C	Log reduction 1.0 to 8.0 cfu/g
Salmonella serotypes ground beef	NaCl 0-4.5% Sodium pyrophosphate 0-0.5% 55 - 70°C	6.5 log cfu/g lethality

Table 6
Additional models included in pathogen modelling program - stand-alone version 7.0 not available via online

Model	Temp (°C)	Nacl (% aq)	Aw	pH	Initial level log cfu/g	Other conditions
Salmonella	10 - 30	0.5 - 4.5	0.997 - 0.974	5.6 - 6.8	3.0 - 5.9	N/A
Listeria monocytogenes Aw (aerobic)	4 - 37	-	0.928 - 0.997	4.5 - 7.5	3.0 - 5.9	Sodium nitrite 0 - 150ppm
Listeria monocytogenes Aw (anaerobic)	4 - 37	0.5 - 5.0	0.997 - 0.97	4.5 - 8.0	3.0 - 5.9	Sodium nitrite 0 - 150ppm
Yersinia enterocolitica aerobic	5 - 42	0.5 - 5.0	0.997 - 0.970	4.5 - 8.5	3.0 - 5.9	Sodium nitrite 0 - 150ppm

Thermal inactivation

	Temp (°C)	Nacl (%)	Aw	pH	Other conditions
Non proteolytic *C. botulinum* in turkey slurry	70 - 90	0 - 3	1.00 - 0.983	5 - 7	Sodium pyrophosphate 0 - 0.3%
E. coli O157:H7 in simulated beef gravy	55 - 62.5	0 - 6	1.00 - 0.963	4 - 8	Sodium pyrophosphate 0 - 0.3%
Listeria monocytogenes in ground beef	55 - 65	0 - 6	1.00 - 0.963	4 - 8	Sodium pyrophosphate 0 - 0.3%

Survival models

	Temp (°C)	Nacl	Aw	pH	Other conditions
E. coli O157:H7	4 - 37	0.5 - 15	0.997 - 0.887	3.5 - 7.0	Lactic acid 0 - 2%, $NaNO_2$ 0 - 75ppm
L. monocytogenes (NaCl)	4 - 42	0.5 - 19	0.997 - 0.845	3.2 - 7.3	Lactic acid 0 - 2%, $NaNO_2$ 0 - 150ppm
S. aureus	4 - 37	0.5 - 20	0.997 - 0.834	3.0 - 7.0	Lactic acid 0 - 1%, $NaNO_2$ 0-200ppm
Salmonella	5 - 42	0.5 - 16	0.997 - 0.887	3.5 - 7.2	$NaNO_2$ 0 - 200ppm

Other models

Model	Model Capability
Salmonella Typhimurium irradiation	Predicts decline in numbers following 0 - 3.6kGy treatment of chicken
E. coli O157 irradiation	Predicts decline in numbers following 0 - 2.0 kGy treatment in beef tartar
Spoilage flora (chicken leg) irradiation	Predicts decline in numbers following a 0 - 3.6kGy treatment in chicken meat
Time to turbidity proteolytic *C. botulinum*	Predicts probability of growth at 15 - 34°C, pH 5 - 7.2, Nacl (%) 0 - 4
Non proteolytic *C. botulinum*	Predicts probability of growth at 5 - 28°C, pH 5 - 7.0, 0 - 4% Nacl
Time to toxin production for *C. botulinum* in fish	Lag time predicted at 4 - 30°C, initial spore level -2 - 4.0 log cfu/g and initial aerobic count -2 - 3.0 log cfu/g

Table 7
Other modelling systems

Model	Model Capability
Seafood spoilage predictor http://fssp.food.dtu.dk/	Predicts shelf life and growth of organisms relevant to seafood
E.coli in fermented meat model http://www.foodsafetycentre.com.au/fermenter.php	Predicts inactivation in fermented meats
Microbial response viewer http://mrviewer.info/	Database containing growth/no growth data
MLA Refrigeration Index calculator http://www.foodsafetycentre.com.au/refrigerationindex.php	Predicts likely growth of *E.coli* in meat